Authors’ response to the anonymous referee #1

Moein Mohammadi, Jakub L. Nowak, Guus Bertens, Jan Moláček, Wojciech Kumala, and Szymon P. Malinowski

We are grateful to the referee for the insightful comments and suggestions on our manuscript. We respond to them in detail below. The original review is given in black, and the answers in blue. The responses mention also specific corrections which were applied to the manuscript.

1. In the introduction of the coincidence filter, it would be good to explain why this effect happens. If I understand correctly, you assume that there was only one droplet, but it got somehow recorded twice by the instrument and you only keep the average size and velocity. Could actual coincidence also be a contributing factor, if two droplets (or fragments) pass the sample volume? Since other instruments have issues with recording two drops at a time, it would be worth noting.

   Typically in instruments which count droplets one-by-one, a measurement artifact known as "coincidence" occurs when more than one droplet are registered at the same time resulting in multiple droplets artificially measured as one droplet. With a rise in droplet number concentration, the coincidence also increases. It has been extensively studied for Forward Scattering Spectrometer Probe (FSSP), Cloud Droplet Probe (CDP), and Cloud and Aerosol Spectrometer (CAS) (e.g. Cooper, 1988; Burnet and Brenguier, 2002; Lance et al., 2010; Lance, 2012). An optical modification was applied to the CDP by Lance (2012) in order to reduce over-sizing and under-counting biases due to coincidence.

   On the other hand, for the PDI as the probe volume, which is defined by the intersection of two laser beams, can be easily reduced, the occurrence of coincidence is expected to be less likely. The probe volume diameter of the PDI, which is determined by the beam diameter, laser wavelength, and transmitter focal length, has been optimized by the manufacturer to minimize the coincidence error. For instance, the probe volume for a typical cloud droplet size of 15 μm is estimated to be smaller than 10^{-5} cm^3. Considering a dense cloud with a droplet number concentration equal to 1000 cm^{-3}, the average number of droplets within the probe volume would be less than 0.005. Hence, assuming a homogeneous droplet distribution (i.e. disregarding droplet clustering), the probability of having more than one droplet in probe volume, given by a Poisson distribution, would be less than 0.000012. Consequently, the occurrence of coincidence is presumably unlikely.

   Nevertheless, the effects of possible coincidence on PDI data have been discussed in Chuang et al. (2008). If the coincident droplets have similar sizes it is quite likely that both would be rejected by the PDI since the Doppler burst and phase differences in this case would be different than what should appear for a single droplet. Conversely, if the difference in sizes of coincident droplets would be high, the signal from the larger one would be usually dominant and it would be detected, while the smaller droplet is missed. Hence, the under-counting of the small and mid-sized droplets in cloud can be the consequence of coincidence, while the large droplets are counted accurately by the PDI.

During our measurements at the UFS, however, we faced coincidence phenomenon in a slightly different way than mentioned above. In raw data of cloud droplets collected by the PDI, simultaneously recorded counts were found with identical detection times. Their size and velocity values were similar with differences usually less than 2.0 μm and 0.1 m.s^{-1}, respectively. Since these coincident counts with similar sizes were recorded instead of being rejected, we assumed they are actually one droplet recorded more than once by the PDI, which is considered a consequence of multiple triggering in Chuang et al. (2008) research. This error was attributed to the noisy environment by Chuang et al. (2008) which in our case could be the droplets flow passing between the transmitter and probe volume resulting in fluctuations of laser light intensity at the beam intersection. In order to reduce its effect on the results, we have used a coincidence filter in which all simultaneously recorded counts are averaged in size and velocity. It should be also noted that the coincidence filter does not correct the data for the improbable events of multiple droplets simultaneously present in the PDI probe volume.

Following the referee's suggestion, the above mentioned explanation has been also included to the manuscript in Section 2.2.3.

2. For Figure 5, a size distribution of dNdlogd would be more useful. This way, it would be easy to see at which sizes the two instruments deviate. Since they seem to match in panel d, a dNdlogd size distribution would also show agreement there and show a deviation for smaller sizes. This would also show a comparison in the number concentration. Right now, it is not easy to see from panel a if the PDFs should be shifted or if one instrument detects less particles than the other; that only becomes obvious when considering panel d. This way, you could also include both methods for the PDI to show if those two have the same size distribution but shifted up/down (due to the different sample volume) or if they are skewed. It would help to also understand table 3. Probably the size distributions in Figure 5 only match for very large cutoff because D_{min} should not be a sharp cutoff of the PDI, but it might miss smaller droplets gradually?

The authors generally concur that providing size distribution of dN/dlogD is useful as it combines the information regarding both droplet size distribution (DSD) and droplet number concentration (DNC) in one plot. However, at that point in the manuscript, we focused more on the comparison of cloud droplet sizing properties between the two instruments. Using the probability distribution function (PDF) allows us to merely compare sizing performances between the VisiSize and the PDI. The inaccuracy in estimation of the sample volumes of the instruments which directly affects the DNC (and the LWC) results does not influence the PDFs. Hence, this comparison would be independent of the estimation of sample volumes whose effects on the DNC and LWC results has been discussed in detail later in the manuscript (Sections 4.4 and 4.5). We have added a short explanation with respect to the above mentioned point within the manuscript.

Moreover, to elaborate on referee's comment, the dN/dlogD size distributions for Fig. 5 in the manuscript is shown in Fig. 1 here. In this illustration, considering the whole droplet size range, the distributions seem to be shifted between the instruments. However, it must be noted that it can be either due to the different sizing properties or due to the inaccuracy of sample volume estimation which affects the DNCs. The main cause can not be confidently determined, but the different trends below and above $\sim$13 μm cutoff can be observed. Below $\sim$13 μm, the size distributions between the instruments do not match properly even allowing for a vertical shift due to different sample volume estimates or horizontal shift due to sizing bias. On the other hand, above the $\sim$13 μm cutoff, the size distributions seem to be similar especially between the two different PDI methods with a vertical shift which can be attributed to the different sample volumes. This observation can agree with the result of PDF plots comparison in Fig. 5 where it was found that the PDI can be less sensitive in detection of small droplets.

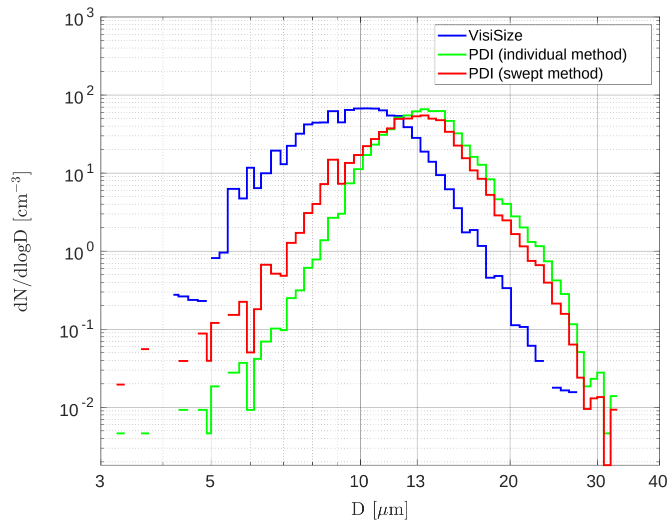

Fig. 1 Comparison between cloud droplet size distributions collected with the VisiSize and the PDI probe (analysed with two different methods) during a measurement on 13th July 2019 15:36-15:51.

3. In Figure 10 especially in panel A the fit does not seem to be very good for large sizes. Why did you choose polynomial, not a different shape, and how many terms did you keep for the polynomial fit?

   We agree with the referee's point regarding the fact that the polynomial fit performance was not satisfactory over the whole size range in panel (a). In fact, the fit curve was only added to emphasise a trend that seems to be present in the data, and there was no physical reason behind choosing it. In the revised manuscript, Fig. 10 is plotted using semi-logarithmic scale (see Fig. 2 here). Subsequently, a reciprocal fit ($\frac{a}{x+b}$) is also plotted to better show the trend in the DNC ratio as the mean droplet size increases.

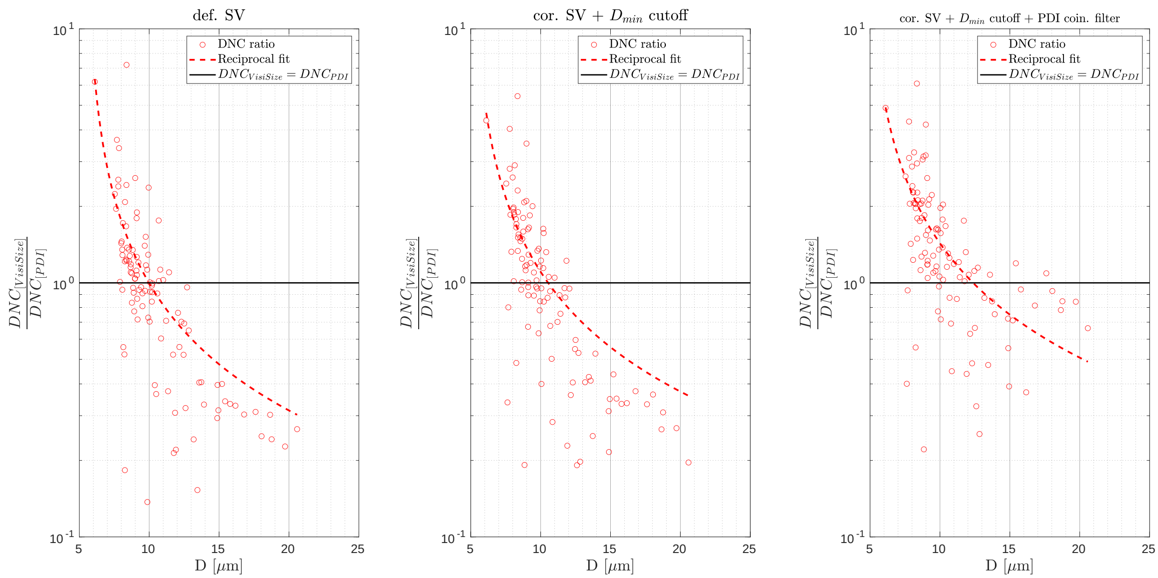

Fig. 2 The DNC ratio of the VisiSize to the PVC-PDI as a function of the arithmetic mean diameter size. Panels from left to right show the raw data (using the default sample volume for the VisiSize), the results after the SV correction and the D_{min} cutoff, and the results after additionally applying the coincidence filter to the PDI data. Each circle represents a single measurement of ∼15 min long. The reciprocal fit curves ($y = \frac{a}{x+b}$) and the 1:1 ratio are shown with the dashed and black horizontal lines, respectively.

4. For general presentation I would suggest increasing the size of some figures for better readability and decrease the amount of white space between them, such as in figure 13. It looks very cramped, but there is plenty of white space to be used between the panels.

   Following the referee's suggestion, all the figures in Sections 4.4 and 4.5 have been demonstrated in logarithmic scale to be able to better show the data points and trends. Moreover, the extra white spaces between the panels of each figure have been erased as much as possible.

5. – Equation 2: τ_{Tot} was not introduced.
   – Line 121-122: grammar (missing an "and" or something similar)
   – Line 316: typo: "because"

   We appreciate pointing out the above mistakes. They have been corrected in the revised manuscript.

References

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